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The U.S. Navy presently has two sea ice forecasting systems running on a daily operational schedule at the Fleet Numerical Oceanography Center. The first forecast system, the Polar Ice Prediction System (PIPS), covers the Arctic basin, the Barents Sea and the Greenland Sea using 125 km grid resolution. The second model, the Regional Polar Ice Prediction System - Barents (RPIPS-B), cover the Barents Sea and western half of the Kara Sea using 23 km grid resolution. Both models are forced by atmospheric forcing from the Naval Operational Global Atmospheric Prediction System and monthly mean geostrophic ocean currents and deep ocean heat fluxes. The models are run daily making 120 hour forecasts of ice ~~drift~~, ice thickness and ice concentration. Both models are updated, once per week, by assimilating digitized concentration data from the Naval Polar Oceanography Center. Accuracy in the digitized data as well as the timeliness of the data are shown to have a serious impact on the model forecasts.

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Present Methods of Data Assimilation in the U.S. Navy's Sea Ice Forecasting Models.

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ABSTRACT
The U. S. Navy presently has two sea ice forecasting systems running on a daily operational schedule at the Fleet Numerical Oceanography Center. The first forecast system, the Polar Ice Prediction System (PIPS), covers the Arctic basin, the Barents Sea and the Greenland Sea using 127 km grid resolution. The second model, the Regional Polar Ice Prediction System - Barents (RPIPS-B), covers the Barents Sea and the western half of the Kara Sea using 25 km grid resolution. Both models are forced by atmospheric forcing from the Naval Operational Global Atmospheric Prediction System and monthly mean geostrophic ocean currents and deep ocean heat fluxes. The models are run daily making 120 hour forecasts of ice drift, ice thickness and ice concentration. Both models are updated, once per week, by assimilating digitized concentration data from the Naval Polar Oceanography Center. Accuracy in the digitized data as well as the timeliness of the data are shown to have a serious impact on the model forecasts.

1. INTRODUCTION

The Polar Ice Prediction System (PIPS), the U.S. Navy's sea ice forecasting system, is used to predict ice drift, ice thickness and ice concentration in the Arctic basin, Barents Sea and the Greenland Sea. The Regional Polar Ice Prediction System - Barents (RPIPS-B) is a higher resolution (25 km versus 127 km) forecasting system designed specifically for the Barents Sea. The forecasting of sea ice characteristics, such as ice concentration and ice edge, can prove valuable to both commercial and naval operations.

In recent years, our capability to forecast the ice cover in the Arctic has greatly improved. The development of sophisicated large scale ice and coupled ice-ocean models as well as the development of sophisticated global and polar atmospheric models has provided the framework for Arctic forecast systems. Another vital component to any forecast system is an accurate initialization (analysis) field. The accuracy of any forecast will be improved if it is initialized from the most realistic available data. The initialization field would ideally be derived from an abundant source of real time data, which through techniques such as optimum interpolation, would place the data on the model grid. Unfortunately, the hostile Arctic environment does not provide a large source of data, real time or otherwise. This situation will improve in the future when various sources of remotely sensed data, such as active and passive microwave data, become available in near real time.

In this paper, we will discuss present methods of initialization used by PIPS. Advantages and the drawbacks of this method will be presented as well as suggestions for improvements to the model

2. FORECAST SYSTEM DESIGN/MODEL INITIALIZATION

The design of the forecast system is shown in Fig.1 and the PIPS model grid is shown in Fig. 2. PIPS is based on the Hibler ice model (Hibler 1979, Preller and Posey, 1989) and is driven by atmospheric forcing from the Naval Operational Global Atmospheric Prediction System (NOGAPS). The oceanic forcing used to drive PIPS is composed of monthly mean ocean currents and oceanic heat fluxes derived from the Hibler and Bryan ice-ocean model (Hibler and Bryan, 1987). The regional forecast system, RPIPS-B, has the same design as PIPS but uses higher grid resolution. The regional model also uses the ice thickness information derived by PIPS as a boundary condition for its open boundaries. Both models are run each day at the Fleet Numerical Oceanography Center (FNOC) making a 120 hour forecast using a 6 hour time step.

Each day the model forecast is initialized from the previous day's 24 hour forecast. Once per week the model is initialized with ice concentration data from the Naval Polar Oceanography Center (NPOC). This ice concentration data is created by a subjective blending of all available visible and infrared imagery, passive microwave data, Geosat altimeter ice index data as well as any available ship observations over a period of a week. The ice concentration analysis for both the eastern, Fig. 3a, and western (not shown) Arctic is made available on Tuesday of each week. Once the analysis shown in Fig. 3a is available, it is hand digitized by NPOC and transmitted to the FNOC. This data undergoes a series of quality control tests performed by both NPOC and FNOC. These tests are usually completed and the data is available for model initialization by Friday or Saturday of each week. Figure 3b shows the resultant digitized analysis interpolated to the model grid. Note that concentration values in the central Arctic are 100% while the concentration values near the ice edge go from 100% to 0%, or open water, very abruptly thus creating the large gradient in ice concentration contours near the ice edge.

The model initialization procedure, in use at this time, is very simple. On the "update" day, the model's 24 hour forecast from the previous day is read in as usual. However, the model's 24 hour forecasted ice concentration field is totally replaced by by the digitized NPOC ice concentration data. In order for the model to assimilate and run with this new data, two additional fields from the 24 hour forecast must be slightly adjusted, the ice thickness and the mixed layer temperature. The ice thickness field is adjusted in the following way: ice thickness is set equal to zero at grid points where the initialization field indicated there was no ice but the model forecast contained ice. In the opposite situation, where the model had no ice but the initialization data indicated there was ice, a small amount of ice is added to the grid cell based on the following simple relationship:

$$H = 0.5 \text{ m if } A < 50\%$$

$$H = 1.0 \text{ m if } A \geq 50\%$$

where H is the ice thickness and A is the ice concentration. Due to the higher resolution of RPIPS-B a smaller amount of ice, 0.2 or 0.4 m is added to the system. The mixed layer temperature is adjusted in the following way: if the initialization field says there is no ice where the model derived field grew ice, the mixed layer temperature of that grid cell is set to approximately 1 degree above freezing. If the initialization field indicates that there is ice in a grid cell which the model previously showed had open water, the mixed layer temperature of that grid cell is set to the freezing point. The adjustments to these fields are usually required only on grid points near the ice edge.

This method of model initialization and data assimilation has been successfully used in PIPS since 1987 and in RPIPS-B since October of

1988. It should also be pointed out that at this point in time, the weekly ice concentration analysis from NPOC is the only data set available weekly for updating an Arctic forecast system.

3. CONCLUSIONS

Over the past few years, results using this initialization scheme have been monitored by NORDA. A number of interesting trends have become apparent during this time. First, the model has shown that it is capable of assimilating this data and running in a stable manner at all times. This is a very promising characteristic of the model, particularly since we intend to incorporate more data into the model in the near future. The assimilation of the NPOC data has also been observed to result in better forecasts of the ice edge in most of the cases which have been studied.

It has also become apparent, that there is room for improvement in the present method of initialization. Hand digitization of the NPOC data can result in "human error" in the initialization field. Certain errors, such as the incorrect location of the ice edge, may not be caught by the existing methods of quality control. These errors, when incorporated by the forecast system, can be responsible for an erroneous forecast. With improved computerized analyses, which are planned to begin this year at NPOC, much of this subjective aspect of the analysis and digitization will be removed. It has also been noted that the ice concentration values for the central Arctic are always 100%, winter or summer, in the NPOC data. This is due to a lack of observational data in this area. A concentration of 100% is a good assumption for the central Arctic in the winter, but may not be a good representation of the central Arctic in summer. PIPS has been shown to forecast variable ice concentration in the central Arctic in the summer before its concentration field is changed by the initialization procedure. Future plans call for a blending of the model derived ice concentration with the NPOC analysis to result in a more accurate initialization field (see Cheng and Preller in these proceedings). While monitoring the PIPS and RPIPS-B results, it has become apparent, that the timeliness of the data is another problem. The NPOC analysis is composed of data accumulated of the period of one week. Thus the analysis which is available on Tuesday, may contain characteristics of the ice concentration which are a week old. The time taken to digitize and quality control the data adds another three to four days to the age of the data. As a result, the data used to initialize the model could be as much as 10 days old. At certain times of the year, such as mid winter, a 10 day delay may not cause serious problems in the forecast. But at other times, such as the spring and fall transition periods, a 10 day delay may cause serious errors in the forecast. In the future, this time delay in the data will be corrected in two ways. First, the improved computing techniques applied by NPOC to their analysis during the next year may also result in the availability of more frequent analysis fields. In addition, the availability of SSM/I ice concentration data at FNOC, may provide more near real time data to PIPS.

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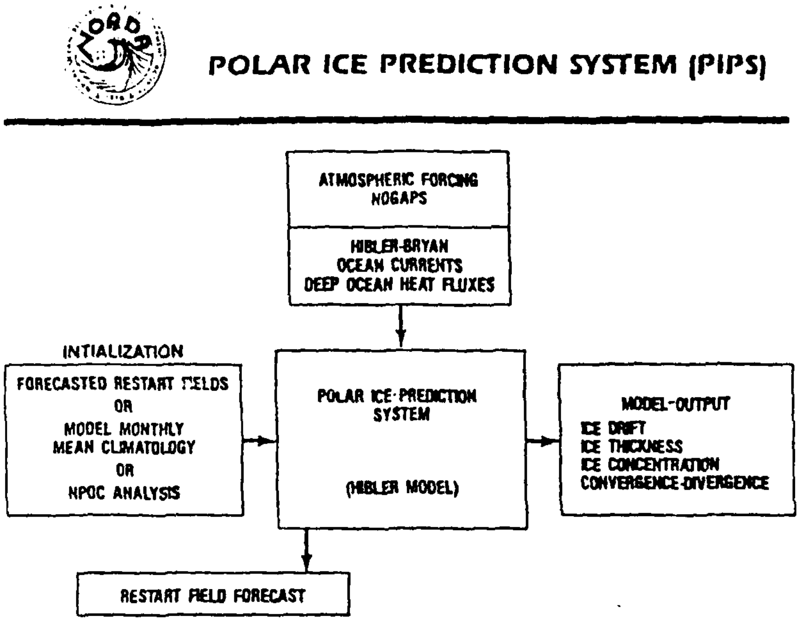

Figure 1. Schematic design of the Polar Ice Prediction System (PIPS).

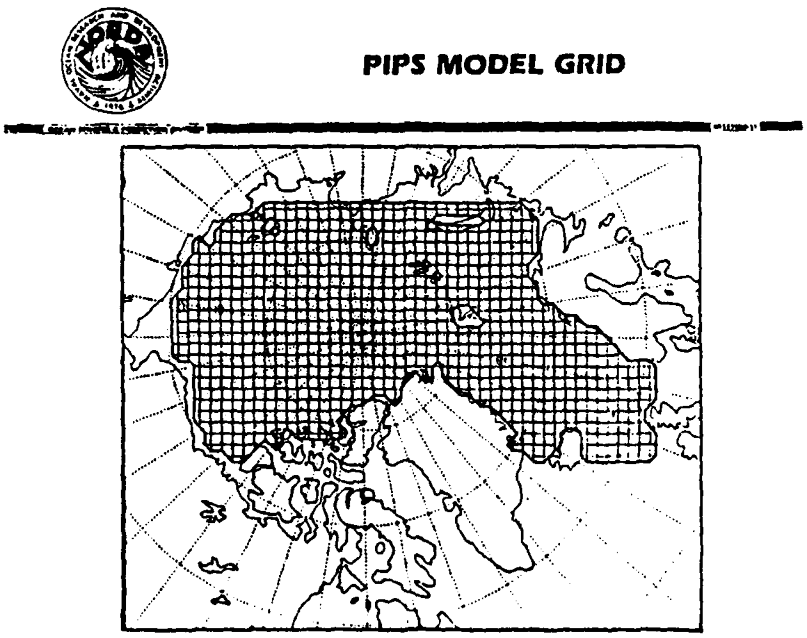

Figure 2. PIPS domain with the 127 km grid.

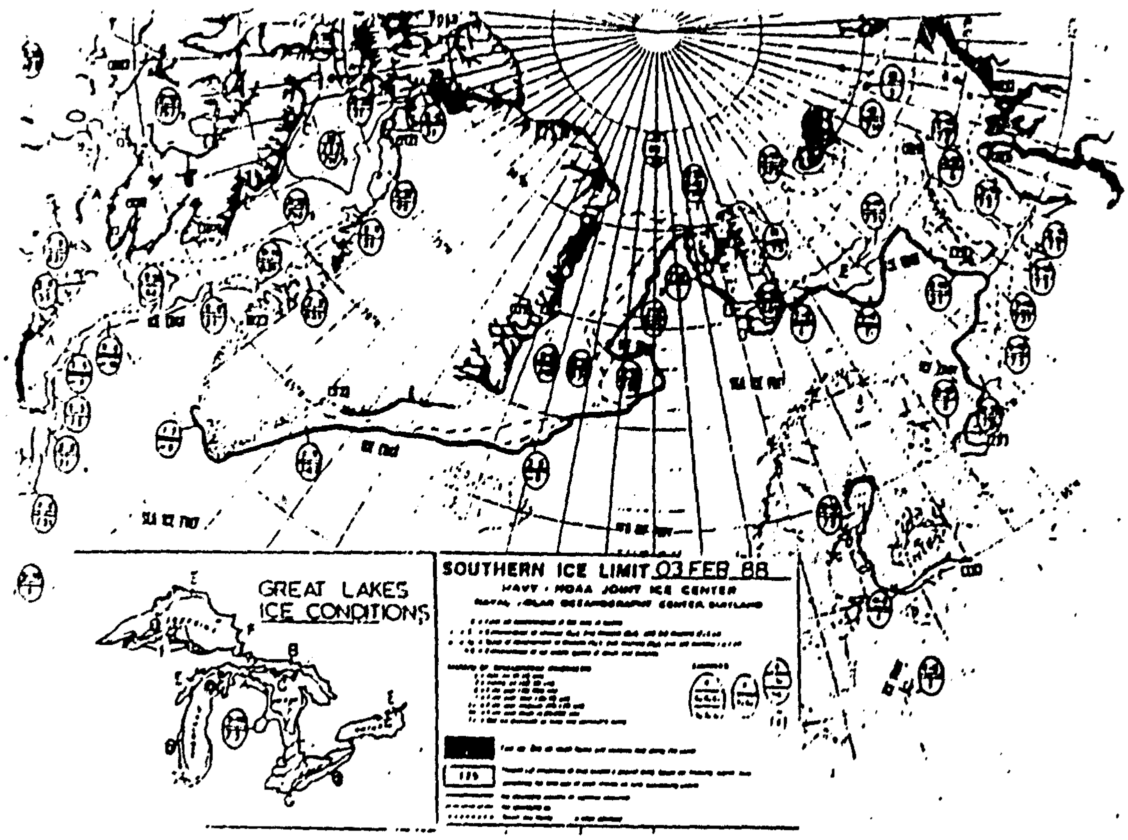

Figure 3a. Eastern Arctic ice concentration analysis for February 3, 1988 from NPOC.

ICE CONCENTRATION

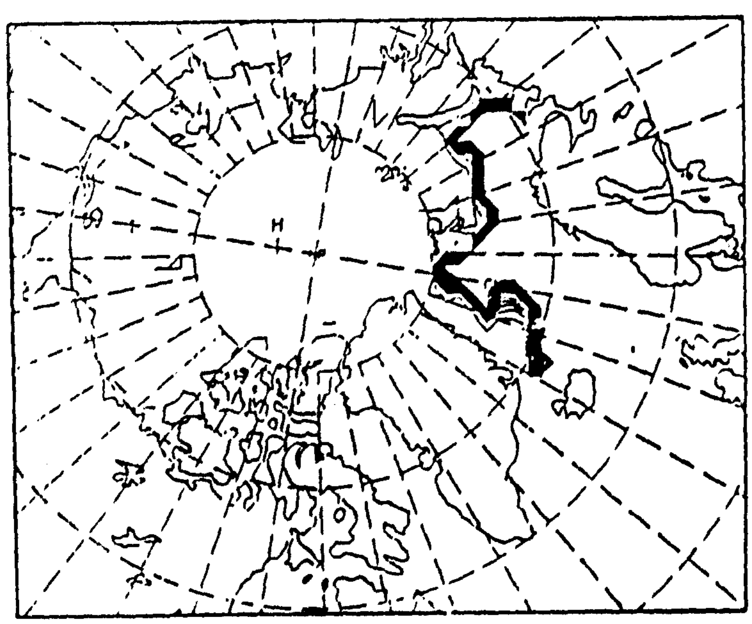

Figure 3b. The corresponding analysis field interpolated to the PIPS grid.